

LCA Case Studies

Life Cycle Assessment of Wood Floor Coverings

A Representative Study for the German Flooring Industry

Barbara Nebel^{1,2*}, Bernhard Zimmer³ and Gerd Wegener¹

¹ Technical University Munich, Department for Biogenetic Products and Technology of Land Use, Wood Research Munich, Winzererstrasse 45, 80797 Munich, Germany

² Now: New Zealand Forest Research Institute Limited, Private Bag 3020, Rotorua, New Zealand

³ University of Applied Sciences, Holztechnikum Kuchl, Markt 136, Austria

* Corresponding author (barbara.nebel@forestreresearch.co.nz)

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Abstract

Goal, Scope and Background. The goal of the study is a life cycle assessment according to ISO 14040–14043 for wood floor coverings (solid parquet, multilayer parquet, solid floor board and wood blocks). The representative study covers approximately 70% of all wood flooring production in Germany. The comparison of the floor coverings among each other was not the aim. Instead the study provides basic data for all wood floor coverings for a possible comparison with other floor coverings later on. The main focus was a hot spot analysis to help the involved industry partners to improve their environmental performance, and to use the results for marketing purposes.

Inventory Analysis. The study covers the whole life cycle from forest management, sawmilling, manufacturing, laying and surface finishing through to refurbishment and end-of-life. The end-of-life scenario is the thermal utilisation of the floor coverings. The energy gained in the end-of-life scenario is accounted for by system expansion (avoided burden approach).

Impact Assessment. In the Impact Assessment the following categories were considered: global warming (GWP), acidification (AP), eutrophication (EP), ozone depletion (ODP) and photo-oxidant formation (POCP) following the CML baseline 2000 method. Furthermore the use of primary energy is presented. The low emissions of greenhouse gases during the life cycle can lead to a negative contribution to the global warming potential if more emissions are avoided through the substitution process than are emitted during the life cycle of the product. Mainly energy consumption and the use of solvents influence the environmental impacts of the systems under analysis. The most relevant unit processes for the issue of energy consumption are 'production' and for photo-oxidant formation 'laying', 'surface finishing' and 'refurbishment'. These are therefore the unit processes with the greatest potential for improvement.

Normalisation and Sensitivity Analysis. The normalisation results show that the photo-oxidant formation potential is most significant in comparison to the other impact categories. Improvement options and the choice of the functional unit have been further explored in a sensitivity analysis.

Discussion and Conclusions. The most important opportunities for improvements are located in the unit processes laying, surface finishing and refurbishment. The POCP result can be reduced significantly depending on the choice of glue and varnish

at each of these stages. The results of the sensitivity analysis showed a potential for improvement in this category. No data for the production of an oil and wax finish was available. This option would be interesting to consider at in a further study. The time aspect of storing CO₂ for a period of time is not considered in this paper, but will be addressed in a forthcoming paper (Nebel and Cowell 2003).

Keywords: Case studies; floor coverings; German flooring industry; parquet; wood

Introduction

The awareness of consumers about environmentally benign products has risen considerably, and the reputation of wood products as being sustainable is not longer sufficient. According to a survey of the German Federal Environmental Agency the proportion of the population who relied on non-proven marketing statements like 'environmentally friendly' declined from 47% in 1998 to 36% in 2000 (Kuckartz 2000). The Association of Wood Flooring Manufacturers therefore approached the Institute of Wood Research Munich to carry out a representative Environmental Life Cycle Assessment (LCA) of wood floor coverings. Earlier work on wood floor coverings (e.g. Jönsson 1995, Werner and Richter 1997, Jarnehammar 2001) did not represent the situation in Germany or considered only one type of wood floor covering (Günther and Langowski 1997).

The present study is one of the first LCA studies in Germany carried out for the whole life cycle of wood products. Other studies focus on key stages like forest production (Schweinle 1996) or the end-of-life scenario (Speckels 2001).

1 Goal and Scope

1.1 Goal

The goal of the study is an LCA on wood floor coverings according to ISO 14040–14043. The comparison of these floor coverings among each other is not the aim. Instead the study provides basic data for all wood floor coverings for a possible comparison with other floor coverings at a later stage. The main focus has been a hot spot analysis to help the involved industry partners to improve their environmental performance and also to use the results for marketing purposes.

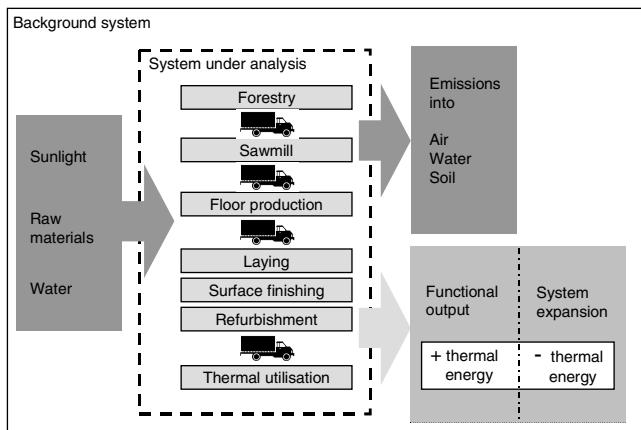


Fig. 1: Life cycle of wood floor coverings, including system expansion

1.2 Scope

The study covers the whole life cycle of wood floor coverings and follows the inputs back to raw materials (Fig. 1). The floor coverings analysed include solid parquet (8 mm, 10 mm and 22 mm thickness), multilayer parquet, solid floor boards and wood blocks (year rings upside). The reference year for the flooring production is 1998.

1.3 System boundaries

The system under analysis includes:

- Manufacturing of glues and varnishes,
- Manufacturing of auxiliaries (e.g. lubricants),
- Provision of energy (e.g. electricity, diesel),
- Maintenance of machinery.

Outside the system boundaries are:

- Production of machinery and infrastructure,
- Human labour.

1.4 Functional unit

The functional unit is defined as 1 m² of laid wood floor covering assuming average wear and tear in a home that is completely refurbished after 50 years. A home is likely to be completely refurbished after 50 years or demolished (Baum 2001). The functional unit represents therefore the useful life-time of a home of 50 years as an effective period of time. The life cycle of the multilayer parquet, which has useful life of 20 years was than multiplied by three, considering

that it has to be produced three times in reality, although in theory it could be used for ten more years.

Regular cleaning of the floor is not included in the functional unit, since this is similar for different floor coverings. Vacuuming once a week however, is considered in the sensitivity analysis.

1.5 Reference flow

The reference flow is defined as the absolute dry mass of wood¹ needed to provide 1 m² of laid floor covering for 50 years (Table 1). This figure is calculated from (exemplified on multilayer parquet):

- Absolute dry mass of one 1 m² (8 kg)
- Loss by laying (4%)
- Useful life (20 years, i.e. 3 life cycles)
- $(8 \text{ kg} + 4\%) \times 3 = 25 \text{ kg}$

1.6 Data quality and data gathering

A working group 'life cycle assessment of wood floor coverings' was established in 1996. Members of the working group include representatives from sawmills and flooring manufacturers, parquet layers, glue and lacquer producers and the association of parquet manufacturers. The main task of the working group was to ensure that the chosen scenarios were grounded in reality and to establish contacts to the flooring industry that lead to coverage of 70% of the German wood floor covering production in the present study.

Most of the data have been measured on site. For some data qualified estimates had to be used; these are indicated in the inventory analysis. Their validity was checked in plausibility checks, based on cross calculations (e.g. if the amount of timber delivered to the plant matches with the sum of products and residual woods) and comparisons with measured data. Data for the first stage of the life cycle 'forestry' and the last one 'thermal utilisation' are based on literature. The sources give sufficient detail about the origin of the data and meet the requirements of the present study. Generic data are based on the database of the GaBi software (PE Europe 2000). Data gathering approaches for other stages of the life cycle are described in the inventory analysis (Section 2).

¹ Although timber is usually measured in volume units, i.e. m³, for calculations in an LCA this is not suitable, due to the special properties of wood. As a natural product it absorbs and releases moisture and expand and contracts. The volume of timber changes therefore throughout the life cycle, whereas the absolute dry mass is constant.

Table 1: Reference flows of the different types of wooden floor coverings

Floor covering	Absolute dry mass/m ² [kg]	Loss at laying [%]	Useful life [years]	Number of life cycles [n]	Reference flow [kg]
8 mm parquet	5.00	1.5	25	2	10.30
10-mm parquet	6.22	3.0	25	2	12.81
22 mm parquet	11.52	3.2	50	1	11.88
multilayer parquet (floated laying)	6.54	3.9	10	5	33.95
multilayer parquet (glued to the ground)	6.54	3.9	20	3	20.39
floor boards	10.71	2.8	50	1	11.01
wood blocks	20.14	1.5	50	1	20.44

1.7 Allocation rules

A characteristic feature of the wood industry is the simultaneous production of various products. For the flooring industry, main products are parquet and constructional timber, and co-products include residual wood. An allocation procedure is only necessary for parquet and constructional timber, since the residual wood is used for the generation of heat and/or electricity on site. The residual wood thus stays within the system under analysis, and no allocation is required.

Whereas most inputs and outputs can be allocated directly to each of the products, some are not specific and allocation rules are needed. In this study the following allocation rules are applied:

Internal transportation: allocation is made according to mass. End-of-life scenario (thermal utilisation): the thermal energy leaves the system under analysis and is used in a different system. According to this delivery of thermal energy, the functional unit would be 'provision of 1 m² floor covering and x MJ thermal energy'. An allocation of all inputs and outputs between these two functions is rather complicated and should be avoided according to ISO 14042. Furthermore the goal definition requires a single function functional unit. System expansion is therefore appropriate. The amount of thermal energy provided by thermal utilisation of 1 m² wood floor covering substitutes the same amount of thermal energy provided with fossil fuels. The emissions from burning the fossil fuels are therefore avoided and thus subtracted from the system under analysis (see Fig. 1) (Werner 2002, Jungmeier et al. 2002).

1.8 Impact categories

The impact categories used in the study are: climate change, ozone depletion, photo-oxidant formation, acidification and eutrophication. Furthermore the use of primary energy is presented. Calculation of the indicator results is based on the characterisation models and category indicators as described in Guinée et al. (2002).

1.9 Critical review

A critical review according to ISO 14040 was carried out by PE Europe GmbH and concluded that the study fulfilled the criteria of ISO 14040–43.

2 Inventory Analysis

The life cycle was divided into the following stages: forestry, saw milling, production of the floorings, laying, use, end-of-life and several transport processes (see Fig. 1). Information on preparation for data collection, data collection itself, summary of the data (according to ISO 14040) are presented together for each stage of the life cycle in sections 2.1 to 2.10 below.

2.1 Forestry

At this stage of the life cycle the production of timber is evaluated. The inventory data are derived from a representa-

tive study of German forestry that considered the four main wood species: oak, beech, spruce and pine (Schweinle 1996).

Included at this stage is the formation of wood by the process of photosynthesis: with solar energy the plants builds wood out of carbon dioxide and water. The carbon dioxide is split up and while the carbon is stored in the wood tissue, the oxygen is returned to the atmosphere. The carbon is released at the end-of-life as carbon dioxide or methane, if the wood rots under anaerobic conditions (e.g. in a landfill). Part of the forestry stage is also the planting of the trees, several thinnings and finally the harvest of the wood using chainsaws and several vehicles. The provision of fuel as well as the emissions are taken into account in the study.

The results of Schweinle's study shows significant differences between the production of the four main wood species.

In order to use the data for the LCA of wood floor coverings it was essential to examine which wood species are processed. Data for species not covered in Schweinle's study (e.g. ash, birch, maple) were assumed to be equivalent to the species with the most similar silvicultural treatment and habit in Schweinle's study, i.e. larch is similar to spruce, whereas maple is similar to beech.

2.2 Transport of the logs to the sawmill

Lorries transport 98% of the logs over a distance of 171 km. Due to the construction of the trucks they can only transport logs (i.e. from the forest to the sawmill) and cannot take a load on the return trip. The average load can therefore not exceed 50%. Train transports the remaining 2% over a distance of 150 km.

2.3 Sawmill

In order to obtain data for the unit process 'sawmill', the processing of 99,543 m³ round timber (hardwoods) was evaluated, which accounts for approx. 25% of the total logs used for the wood floor covering production in the reference year. The same data were used for the processing of softwoods for solid floor boards, wood blocks and the body of multilayer parquet although sensitivity checks based on several studies (Wegener et al. 1997, Speckels et al. 1999) showed that the use of primary energy for the sawmilling of softwood tends to be marginally lower than of the hardwoods considered in this study. The average yield in the analysed sawmills was 64%. The residual wood is used to provide energy which is used within the sawmills.

2.4 Transport of sawn timber

The average distance for the transport of sawn timber for solid parquet is relatively short (Table 2). This is partly due to some manufacturers that have a sawmill on site and sawn timber is only transported on site. No data was available for transports by truck related to transport by train, i.e. from the forest to the station or from the goods station to the manufacturer.

Table 2: Transport of sawn timber, distances and means of transport

	Mode of transport	Truck [km]	Ship [km]	Train [km]	Percentage of transported timber [%]
Solid parquet	Truck	134			90
	Ship	445	7318		10
Multilayer parquet	Truck	331			74
	Ship	662	7,340		7
Solid floor boards	Train			305	19
	Truck	730			85
	Ship	588	5,170		13
Wood blocks	Truck	675		5,497	2
					100

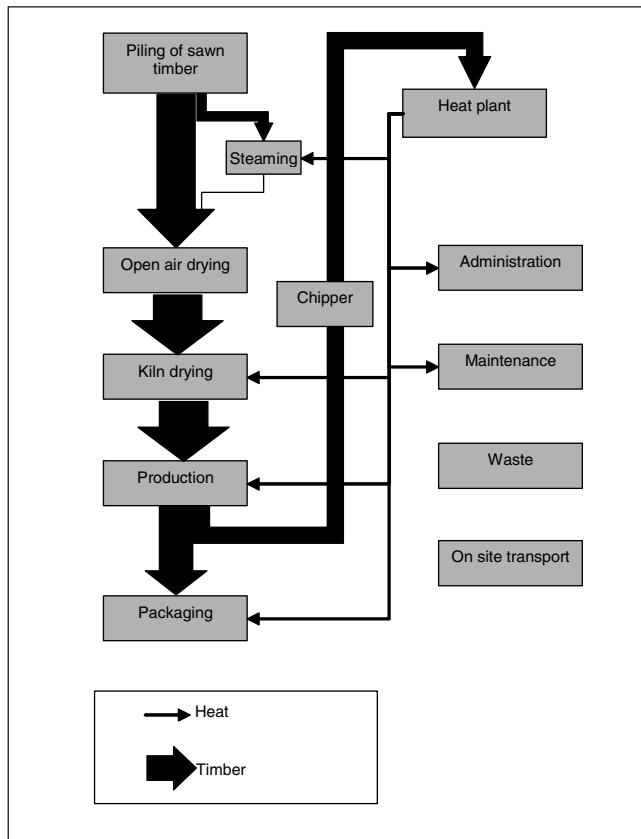
2.5 Floor production

A total of 15 manufacturers were involved in the project. At the beginning of the project a seminar was held, to explain the goal of the study and the contribution of the manufacturers to the project. In order to prepare the data collection on site, the LCA practitioner for the study visited each site and prepared a document for data collection. During this visit subunits were identified in order to facilitate data collection. Staff on site carried out data collection. To obtain an insight into data availability on site and the achievable data quality, the LCA practitioner collected the data on two sites herself. The identified subunits are shown in Fig. 2.

The most energy consuming process is kiln drying the timber. Green timber processed in a sawmill has a humidity of ca. 80% by mass. In order to reduce the shrinking and swelling of the floor coverings, a humidity of 9% is required. Down to around 40 to 25% humidity the drying is achieved by air drying, using solar and wind energy. For the remaining humidity kiln drying is usually applied. For the solid floor board production, air drying was used to reduce the humidity to around 17%. The energy consumption during kiln drying for this kind of floor covering is therefore below the average of the other wood floorings. The proportion of renewable energy however is smaller, due to the primary use of renewable energy for kiln drying (Table 3).

The thermal utilisation of residual wood provides all the heat required for kiln drying and heating the production plants. Between 34% (solid floorboards) and more than 51% (22 mm solid parquet) of the total energy consumption over the whole life cycle is supplied by the energy from the residual wood (excluding the end of life scenario).

The yield of the final floor product varies between 50 and 70% of the input of sawn timber. The varying yield is due to different qualities of timber and the equipment used.

**Fig. 2:** Subunits in the production stage of solid parquet**Table 3:** Primary energy consumption in MJ

	Solid parquet 8 mm [MJ]	Solid parquet 10 mm [MJ]	Solid parquet 22 mm [MJ]	Multilayer parquet [MJ]	Solid floor boards [MJ]	Wood blocks [MJ]
Renewable energy	266	250	275	464	75	228
Fossil energy	275	311	261	467	144	280
System expansion	-6	-8	-8	-36	-7	-15
Total	535	553	528	895	212	493

2.6 Transport of floor coverings

Distances for the delivery of the final products are as follows: solid parquets 340 km, multilayer parquet 500 km, solid floorboards 259 km, and wood blocks 300 km. Data for the distances were gathered from company records.

The difference between the delivery distance for solid parquets and multilayer parquet to retailers is due to the structure of the industry. Solid parquet is produced by a greater number of smaller companies which are regionally distributed, whereas there are only a few big companies producing multilayer parquet.

2.7 Laying and surface finishing

Parquet layers gathered data for laying and surface finishing for single building sites. Together with data from larger companies laying and surface finishing data for approx. 800,000 m² flooring were documented. Energy consumption from sanding was measured on site.

On average three journeys of 17 km with a van to the building site are necessary. The loss at this stage is mainly due to leftovers in packages; it ranges from 1.5% for 8 mm solid parquet to 4% for multilayer parquet.

Whereas parquet and wood blocks are usually glued, solid floorboards are mainly screwed to the ground (ca. 35 g of screws) (Table 4). The option of floated laying for multilayer parquet, where the boards are glued together around the edges rather than to the ground, is also considered (Section 4.2.1). For solid parquet a scenario with waterborne glue is also considered in this study (see Section 4.2.2).

Table 4 shows the options for surface finish for the different kinds of floor coverings. Data for the production of oil and wax were not available, except for the solvent content in the end product. The emission of solvents at the building site was therefore included in the analysis. The production of glues and lacquers was calculated on the base of basic formulations, provided from the manufacturers.

2.8 Use phase

The use phase is divided into refurbishment and cleaning. In order to assess the actual useful life of wood floorings and

the interval between refurbishments, the following information sources were consulted:

- Results of a questionnaire sent to housing companies,
- Court decisions, which say that a tenant can claim a refurbishment after 15 to 20 years,
- Expert knowledge of craftsmen.

The various kinds of wood floor coverings under analysis differ in their useful life. Whereas 22 mm parquet, solid floor boards and wood blocks have a useful life of 50 years, 8 mm and 10 mm parquet have a useful life of 25 years. Consideration of the useful life of multilayer parquet is more complex as it depends on the laying of the parquet. If the parquet is glued to the ground over the whole area, a useful life of 20 years is realistic. If the single boards are glued together around their sides but not glued to the ground (floated laying), a useful life of 10 years is realistic.

The data on sanding and new finishes were based on data collected for the unit processes 'laying' and 'surface finishing'. A refurbishment for all floor types takes place on average every 15 years; it includes sanding of the surface and a new finish. In cases where data from various sources differed, the shorter period was chosen.

For the cleaning of wood floor coverings no hard data are available. An estimation of the impact is based on vacuuming the floor once a week using an average vacuum cleaner (power rating 1000 watt). It takes approx. 12 seconds to vacuum one square metre of hard flooring (Weinberger-Miller et al. 1989). This amounts to a consumption of 8.6 kWh electric power in 50 years, i.e. 105 MJ of primary energy assuming an average German electricity supply. Since the data are highly dependent on consumer behaviour these results are not included in the final results, but mentioned separately in the discussion (Section 3.6). The same issue is discussed in other studies looking at floor coverings (e.g. Jönsson 1999).

2.9 Thermal utilisation at end-of-life

After a useful life of 50 years the wood floor coverings are dismantled and now called 'postconsumer wood'. Forthcoming German legislation will not allow the disposal of postconsumer wood from 2005 onwards and thermal or material utilisation will be the options available (AltholzV

Table 4: Glue and lacquer used per m² of floor covering

Floor covering	Glue ¹ [g/m ²]	Type of glue	Surface finish ² [g/m ²]	Type of surface finish
8 mm parquet	800	93% solvent based glue 7% waterborne glue	330	73% waterborne finish
10 mm parquet	1,100		90/40 300	25% oil/wax finish 2% solvent based finish
22 mm parquet	1,100		140	UV-curing lacquers
Multilayer parquet, glued to the ground	1,100	100% solvent based glue	140	UV-curing lacquers
Multilayer parquet, floated laying	40		90/40	Oil/wax finish
Solid floor boards	1,100	Mainly screwed or nailed	n.a.	No finish
Wood blocks	1,300	100% solvent based glue		

¹ amount of glue is dependent on type of floor covering

² amount of lacquer is dependent on type of lacquer

2002). Frühwald et al. (2000) show that 65% of the collected post-consumer wood is used for energy recovery and only 3% goes currently to landfilling. Since thermal utilisation is the most likely end-of-life scenario for floor coverings rather than material utilisation, this option is chosen for this case study. The data for this stage of the life cycle is based on Speckels (2001).

2.10 Substitution of thermal energy from fossil fuels

The energy gained during thermal utilisation leaves the system boundary as an extra product. Allocation is avoided in this case by the use of system expansion. The best available technology is chosen for the provision of thermal energy from fossil fuels, assuming that this technology will be widely available in the future. The thermal energy from gas with an efficiency of 100% is assumed to substitute thermal energy (PE 2000).

Table 5: Results for the impact assessment

	Solid parquet 8 mm	Solid parquet 10 mm	Solid parquet 22 mm	Multilayer parquet	Solid floor boards	Wood blocks
GWP [kg CO ₂ -equivalent]	7.1	5.9	4.4	12.7	0.2	-2.8
AP [kg SO ₂ -equivalent]	0.103	0.113	0.106	0.223	0.064	0.121
EP [kg PO ₄ ³⁻ -equivalent]	0.0148	0.0161	0.0149	0.0339	0.0098	0.0189
POCP [kg C ₂ H ₄ -equivalent]	0.2821	0.3576	0.2103	0.4904	0.0808	0.2605
ODP [kg R11-equivalent]	0.0000041	0.0000043	0.0000039	0.0000062	0.0000022	0.0000042
Primary energy [MJ]	534	553	529	917	213	494

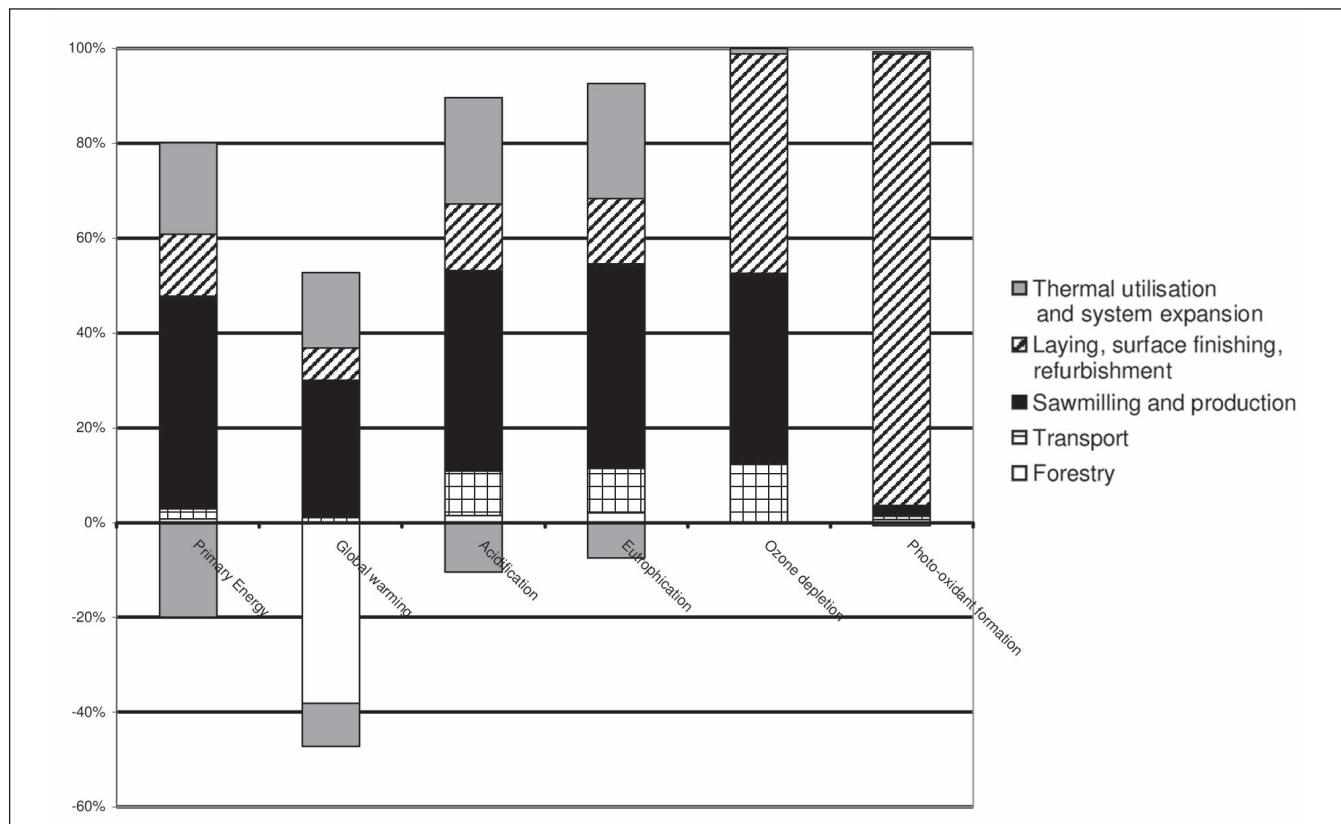


Fig. 3: Relative contribution of each stage of the life cycle to impact categories and primary energy. Results are shown for the average of the six different types of wood floor coverings

life scenario and are therefore shown together. This graph allows the identification of the most significant unit processes.

3.1 Climate change

Due to the extraction of 1.85 t CO₂ from the atmosphere per tonne of absolute dry wood in the wood formation process the results for this impact category are calculated for inputs as well as outputs. This leads to a negative GWP in the first stage of the life cycle, but since all of the carbon is released at the end of life (see section 2.9) the final result comprises a balance of input and output. Additionally the avoided emissions from the system expansion process are subtracted (Fig. 4). For wood blocks this leads to a negative net result; in other words, during the life cycle the GWP of gases released is less than the GWP of gases replaced using the thermal energy gained in the end-of-life scenario.

The life cycle stages making the greatest contribution to the results are stages where the wood is burned (sawmilling, production and thermal utilisation), and the system expansion. The effect of the storage of carbon for period of time is not included in these calculations. However, it should be noted that the magnitude of this contribution is, in reality, dependent upon how one models the time period that the wood continues to fulfill its role in storing carbon (Nebel & Cowell 2003).

3.2 Ozone depletion

The life cycle stages laying, surface finishing and refurbishment contribute 44% of the total result for ozone depletion. About

one third of the results are from the production of the floorings. All transport processes amount to an average of 13%.

Within the production stage about 80% of the ozone depletion potential results from the production of the required electricity. Thermal utilisation and the substitution process play a minor role in this impact category.

3.3 Photo-oxidant formation

The POCP of the system under analysis is mainly caused by VOCs emitted from the solvents in the used glues and surface finishes. Referring to the POCP of the system under analysis, the unit process laying is by far the most important for the parquets, followed by surface finishing and refurbishment. These unit processes together contribute on average 96% to the POCP (Fig. 5). The solvents in glue and varnishes are responsible for the results for these life cycle stages. Since solid floor boards are fixed mechanically to the ground and no surface finish is used their POCP differs greatly from the parquets' POCPs. Wood blocks are glued to the ground, but no surface finish is used. Another interesting value is the comparatively low POCP of the unit process 'surface finishing' for multilayer parquet (Table 5). This is because ultra-violet-radiation curing varnishes, using with almost no solvents, have been applied already in the plant. The influence of glues and varnishes is further investigated in the sensitivity analysis (Section 4.2).

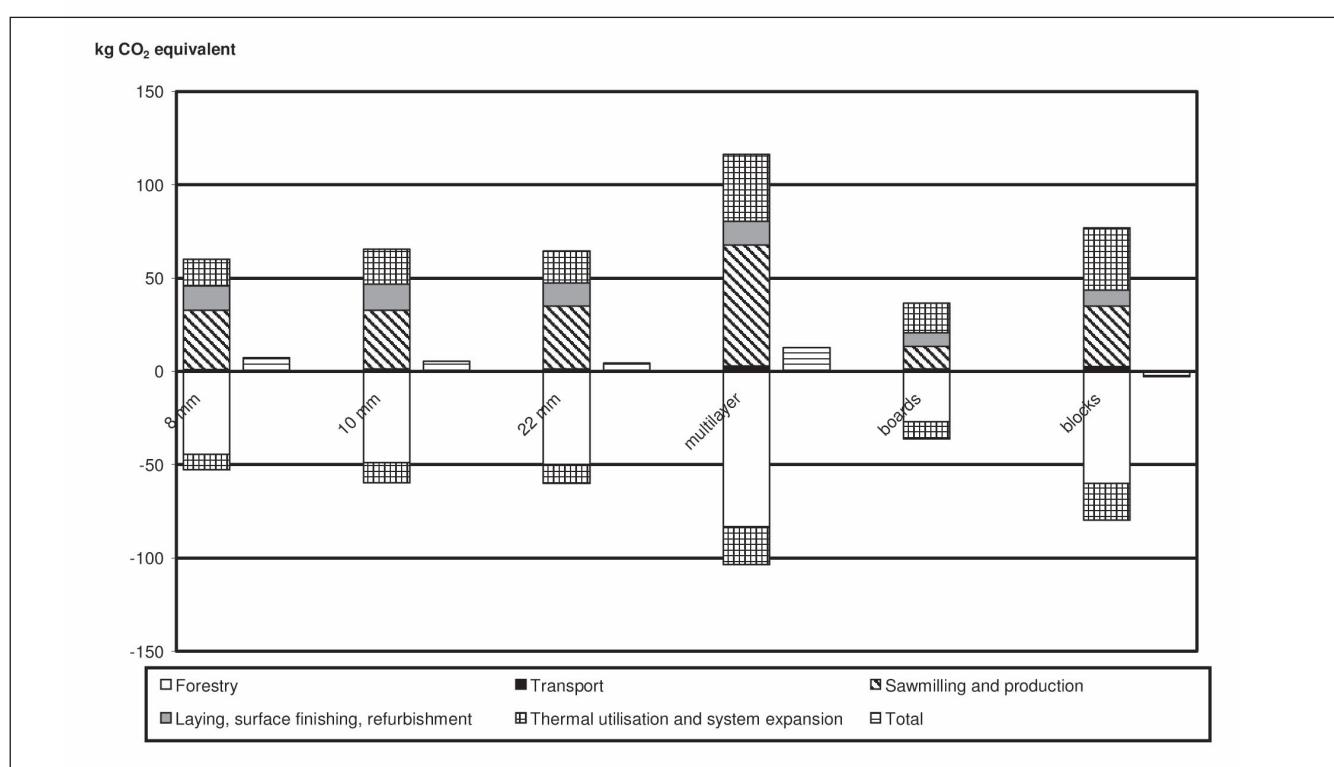


Fig. 4: Impact assessment results for climate change

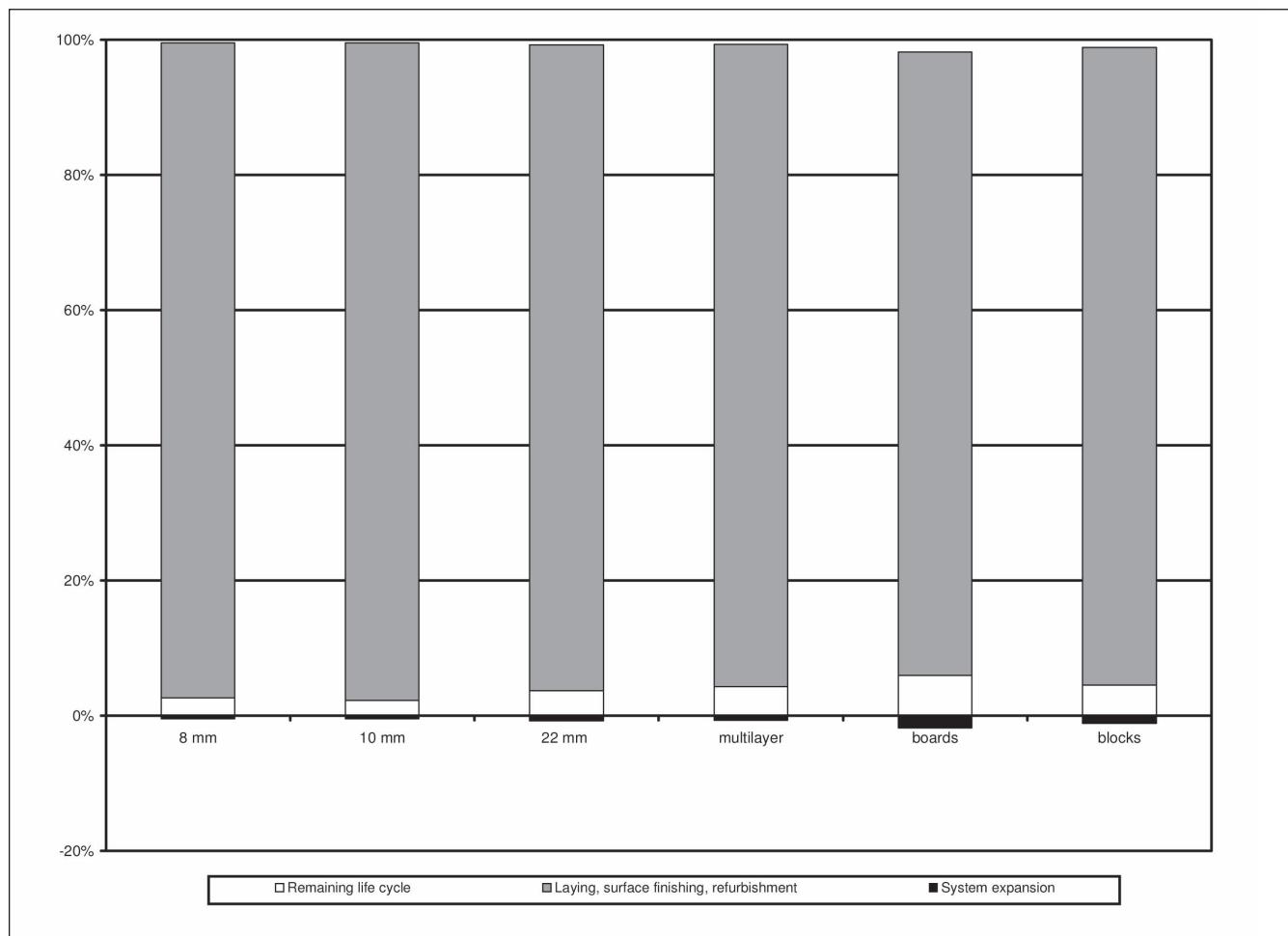


Fig. 5: Impact assessment results for photo-oxidant formation, relative contribution of laying, surface finishing and refurbishment

3.4 Acidification

Nitrogen oxides (NO_x) contribute about 70%, (and sulphur dioxide (SO_2) contributes about 25%) to the results for acidification potential (AP). The NO_x emissions are mainly from the provision of energy in the unit processes production and thermal utilisation, where SO_2 is mainly from the combustion of fossil fuels for the provision of energy but also from transport. The AP in the unit processes laying and refurbishment derives to a large extent from the transport of the workmen to the construction site. Although other transport stages, i.e. transportation of sawn timber, cover a much bigger distance, their influence is comparatively small due to their efficiency. For example, the transport of sawn timber for 8 mm parquet, requires 0.049 kg diesel per functional unit, whereas the transport of the workman to the construction site and back three times requires 0.346 kg diesel.

3.5 Eutrophication

In the system under analysis over 90% of the Eutrophication is caused by nitrogen oxides. Since these are also the main contributors to the acidification potential, the relative contributions of the life cycle stages are similar for both impact categories (Fig. 3).

3.6 Primary energy

Primary energy consumption is shown in Table 3 broken down into energy from renewable and fossil fuels, and related to system expansion. Between 34% (solid floor boards) and 51% (22 mm parquet) of the total energy requirement (excluding system expansion) is provided from renewable energy, i.e. from residual wood.

Within the unit process production, kiln drying and the actual production are the most energy consuming processes. An analysis of the production has shown that there are nearly no differences between the analysed plants and that there is almost no potential to save energy. However, the results for the energy consumption of kiln drying varied quite a lot. In particular the humidity at the starting point has a big influence. Companies that make more use of open air drying achieve lower humidity at the start of the kiln drying and can thus save energy. This effect is clearly shown in the results for solid floor boards. The companies producing floor boards start kiln drying at a humidity of ca. 17%, whereas the parquet manufacturers start between 25% and 40%.

For the system expansion the same amount of useful energy as gained from the end-of-life scenario was provided from fossil fuels. The negative value in the row 'system expansion' results from the difference between useful and primary

energy in the expanded system. The difference is regarded as an avoided burden and therefore it is subtracted from the system under analysis.

The energy consumption for cleaning is not included in these figures. Using an estimated value of 105 MJ this would add between 12% (multilayer parquet) and 50% (solid floor boards) to the total energy consumption.

4 Normalisation and Sensitivity Analysis

4.1 Normalisation

The results are normalised against the total score for each impact category in Germany (Table 6), based on PE-Europe (2000). It was decided to calculate normalised values to represent the entire wood flooring sector in Germany rather than normalised values for each type of wood flooring. The reason was to gain insights relevant for marketing the entire wood flooring sector. Since the different wood floor coverings hold different shares of the market (e.g. multilayer parquet contributes 50% to the total of wood floor coverings in square metres), a weighted average was calculated, i.e. the results for multilayer parquet contribute 50% to the results for the whole sector.

Table 6: Normalisation of results for German wood flooring industry against data for total of Germany

Impact category	Contribution to total of Germany in %
Climate change	0.0002
Acidification	0.0003
Eutrophication	0.0008
Photo-oxidant formation	0.0021
Ozone depletion	0.000002
German GDP	0.01*

* Note: Figure is calculated based on GDP from manufacturing stage of wood flooring industry.

The figures in Table 6 show that the contribution to photo-oxidant formation is relatively high. It is therefore appropriate to focus on this impact category for improvement opportunities.

The relation of the total turnover of the flooring industry to the GDP of Germany shows that the flooring industry contributes ca. 0.01% to the German GDP. As shown in Table

6 the contribution of the wood flooring industry to the impact categories is a factor 5 to 50 below the contribution of the total turnover of the parquet industry to the GDP in the same year. This means that, compared with the financial contribution of the sector to the German economy, the environmental impacts are relatively small. Furthermore, only the production stage of the life cycle is taken into account for the economic comparison; if all stages of the life cycle were considered, the discrepancy would be even higher.

4.2 Sensitivity analysis

Photo-oxidant formation is the impact category with the greatest impact with respect to the overall impact in Germany (see Table 6). Since the greatest contribution to this impact category comes from the life cycle stages laying and surface finishing, these are looked at in the sensitivity analysis.

4.2.1 Floated laying versus glued laying for multilayer parquet

The floated laying option for multilayer parquet influences the results in two ways. Firstly the shorter time span, ten years as opposed to 20 years, for the useful life requires five times the production of the flooring instead of three times. The primary energy consumption is therefore about 20% higher for the scenario with floated laying (Table 7). Consequently the impact categories depending on the primary energy consumption have higher results as well. On the other hand, floated laying requires far less glue and is a type which has comparatively low solvent content. Therefore the contribution to the Photo-oxidant formation is reduced in this scenario by nearly 90%.

4.2.2 Use of different glue and finish in the unit processes laying and surface finishing

The choice of the glue and finish influences the results to a great extent. In the sensitivity analysis different types of glue and finish are analysed. In the basic scenario a solvent based glue and a water based finish are used for 8, 10, and 22 mm parquet, since these are the most widely used alternatives. The sensitivity analysis looks at alternative scenarios using one different glue and one different finish (Table 8).

The replacement of the solvent based glue with a water based, 'dispersion' glue reduces the POCP by about 70%. The combination of a solvent based glue and a solvent based finish increases the POCP by almost 70%.

Table 7: Impact assessment results for multilayer parquet for glued laying versus floated laying

	MJ [MJ]	GWP [kg O ₂ Equiv.]	ODP [CFC11 Equiv.]	POCP [kg C ₂ H ₄ Equiv.]	AP [kg SO ₂ Equiv.]	EP [PO ₄ ³⁻ Equiv.]
Glued	917	12.7	0.0000062	0.49	0.22	0.03
Floated laying	785	44.8	0.0000076	0.05	0.40	0.06

Table 8: POCP potential for different glue and finish scenarios, shown for 8 mm parquet

	Solvent based glue / waterbased finish (basic scenario) [kg C ₂ H ₄ Equiv.]	Waterbased glue / waterbased finish [kg C ₂ H ₄ Equiv.]	Solvent based glue / Solvent based finish [kg C ₂ H ₄ Equiv.]
Laying	0.22	0.02	0.22
Surface finishing	0.03	0.03	0.12
Refurbishment	0.03	0.03	0.12
Total	0.28	0.08	0.47

Table 9: Functional unit of 50 versus 25 years: Influence on the results for 8 mm parquet which has a useful life of 25 years and 22 mm parquet which has a useful life of 50 years

	MJ [MJ]	GWP [kg O ₂ Equiv.]	ODP [CFC11 Equiv.]	POCP [kg C ₂ H ₄ Equiv.]	AP [kg SO ₂ Equiv.]	EP [PO ₄ ³⁻ Equiv.]
8 mm functional unit 50 years	534	7.3	0.0000041	0.282	0.103	0.015
8 mm functional unit 25 years	216	9.1	0.0000020	0.1423	0.060	0.008
22 mm functional unit 50 years	529	4.4	0.0000039	0.2103	0.106	0.015
22 mm functional unit 25 years	473	-0,2	0.0000030	0.1831	0.098	0.015

4.2.3 Functional unit

For long lived products the incorporation of the time aspect in the functional unit is crucial. The functional unit of 50 years accommodates for longer live products. Shortening this period to 25 years leads to 50% lower results for 8 mm parquet due to its useful life of 25 years – in 50 years the whole life cycle is calculated twice. However, for 22 mm parquet, which is produced only once is 50 years, the difference in the results comes from the lower number of refurbishments – in 50 years the floor is refurbished 3 times, in 25 years only once, whereas the number of life cycles stays the same (Table 9).

5 Discussion and Conclusions

Altogether it can be concluded that mainly energy consumption and the use of solvents influence the environmental impacts of the systems under analysis. The most relevant unit processes for the issue of energy consumption are 'production', and for photo-oxidant formation 'laying', 'surface finishing' and 'refurbishment'. These are therefore the unit processes with the greatest potential for improvement.

Differences between the three types of solid parquet are not significant. The thinner ones (8 and 10 mm) have to be produced more often, but for 22 more wood is needed. This is due to the dependency of the energy consumption in the production phase on the mass of wood – especially for kiln drying. The reference flows for the three types don't vary significantly 10.8 kg for 8 mm parquet, 12.8 kg for 10 mm and 11.8 kg for 22 mm parquet (Table 1). The impacts of multilayer parquet, which has a reference flow of 33.95 kg, are relatively high for the same reason. The results for solid floor boards are lower due to the more intensive use of open air drying in the production phase. These results clearly show that more efficient drying of timber would improve the environmental performance of wood products.

Regarding the use of solvents, and particularly their contribution to photo-oxidant formation, a remarkable improvement can be achieved in the unit processes laying, surface finishing and refurbishment. As the sensitivity analysis has shown, the choice of a different kind of glue can reduce the POCP by 70%. Due to the lack of data an oil and wax finish was not analysed in the present study. This scenario would be interesting to look at in a further study.

The impact category climate change shows two interesting issues. Firstly, the provision of energy from post-consumer wood can substitute fossil fuels and makes a difference of up to 52% to the final results, secondly wood floor cover-

ings function as a net storage of CO₂ during their useful life. Therefore the production and use of wood products counteracts climate change in two ways: substitution of fossil energy and storage of carbon. However, the latter needs to be explored in more detail in order to include it in the results of an LCA (Nebel and Cowell 2003).

Looking at long lived products bears some critical points which have to be considered in an LCA. The results of the sensitivity analysis show that the functional unit has to be chosen carefully to allow for products with different useful lives without penalising longer life products. On the other hand user behaviour is another crucial aspect to this study. A shorter service time of the floor coverings would significantly change the results for the different floorings. Another aspect is the actual use phase. Results for the cleaning stage confirm the importance of including the use phase, especially for long-lived products which have a relatively low energy consumption in their production stages.

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LCA Case Studies

Allocation in LCA of Wood-based Products

Experiences of Cost Action E9

Part I. Methodology

Gerfried Jungmeier^{1*}, Frank Werner², Anna Jarnehammar³, Catharina Hohenthal⁴ and Klaus Richter²

¹ JOANNEUM RESEARCH, Institute of Energy Research, Elisabethstrasse 5, A-8010 Graz, Austria

² Federal Laboratories for Materials Testing and Research (EMPA), Dübendorf, Switzerland

³ Trätek, Swedish Institute for Wood Technology Research, Stockholm, Sweden

⁴ KCL, Helsinki, Finland

* Corresponding author (gerfried.jungmeier@joanneum.at)

Preamble. The treatment of allocation is a crucial matter in the LCA of wood-based products, because the allocation method might influence the results significantly. This paper outlines in two parts – **Methodology** (Part I) and **Examples** (Part II) – practical experiences for the treatment of allocations for LCAs of wood-based products that are the result of the Cost Action E 9 'Life cycle assessment of forestry and forest products' and reflect the experience of Cost E9 delegates. Part II will be published in the November issue [*Int J LCA* 7 (6) 369–375 (2002)].

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Goal and Background. The treatment of allocation in the descriptive LCA of wood-based products has been discussed for a long time and different solutions have been presented. In general, it is accepted that the influence of different allocation procedures on the results of LCA of wood-based products can be very significant. This paper is a result of the Cost Action E9 'Life cycle assessment of forestry and forest products' and represents the experience of involved Cost E9 delegates.

Objective. Wood is a renewable material that can be used for wood products and energy production. Consistent methodological procedures are needed in order to correctly address the twofold nature of wood as a material and fuel, the multi-functional wood processing generating large quantities of co-products, and reuse or recycling of paper and wood. Ten different processes in LCAs of wood-based products are identified, where allocation questions can occur: forestry, sawmill, wood industry, pulp and paper industry, particle board industry, recycling of paper, recycling of wood-based boards, recycling of waste wood, combined heat and power production, landfill.

Methodology. Following ISO 14 041 a step-wise procedure for system boundary setting and allocation are outlined. As a first priority allocation should be avoided by system expansion, thus adding additional functions to the functional unit. Alternatively, the avoided-burden approach can be followed by subtracting substituted functions of wood that are additionally provided. If allocation cannot be avoided, some allocation methods from case studies are described.

Conclusions. The following conclusions for allocation in LCA of wood-based products are given. 1) Avoid allocation by expansion of system boundaries by combining material and energy aspects of wood, meaning a combination of LCA of wood products and of energy from wood with a functional unit for products and energy. 2) Substitute energy from wood with conventional energy in the LCA of wood products to get the functional unit of the wood product only, but identify the criteria for the substituted energy. 3) Substitution of wooden products with non-wooden products in LCA of bioenergy is not advisable, because the substitution criteria can be too complex. 4) If avoiding allocation is not possible, the reasons should be documented. 5) Different allocation procedures must be analysed and documented. In many cases, it seems necessary to make a sensitivity analysis of different allocation options for different environmental effects. It can also be useful to get the acceptance of the chosen allocation procedure by external experts. 6) Different allocation factors, e.g. mass or economic value, are allowed within the same LCA. 7) For allocation of forestry processes it is necessary to describe the main function of the forest where the raw material is taken out. In some cases different types or functions of forests must be considered and described. 8) Regarding the experiences from the examples, the following most practical allocation for some specific processes are identified: forestry: mass or volume; sawmill: mass or volume and proceeds; wood industry: mass and proceeds.